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Walking trajectory in neglect patients

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Abstract

A lateral deviation of the walking trajectory is often observed in stroke patients with unilateral spatial neglect. However, existing research appears to be contradictory regarding the direction of this deviation. The aim of the present study was to gain more insight into the walking trajectory of neglect patients. Twelve right hemisphere stroke patients (six neglect, six no neglect), eight left hemisphere stroke patients (none neglect) and 10 healthy control subjects were instructed to walk towards a target while a two-dimensional ultrasonic positioning system recorded their walking trajectory. Patients' recovery of walking ability was assessed and they were tested for the presence of neglect. Neglect patients showed a larger lateral deviation in their walking trajectory compared to stroke patients without neglect or controls. Neglect patients with good walking ability showed a deviation to the contralesional side. Neglect patients with limited walking ability showed a deviation to the ipsilesional side. Within the neglect group we found no relation between the severity of neglect and lateral deviation. Differences in walking ability may account for the contradictory results between studies regarding the lateral deviation in neglect patients' walking trajectory. We suggest that when a neglect patient's walking ability is limited, walking towards a target becomes a dual task: heading control and walking. A limited walking ability will cause a higher task priority of walking compared to heading control. This shift in task priority may be causing the change in walking trajectory deviation.

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1. Introduction

Many studies have shown that the presence of unilateral spatial neglect (USN) is associated with poor outcome after stroke and impedes functional recovery [1–5]. USN is a disorder in which patients fail to attend to the contralesional side of space or their body and this failure cannot be explained by primary sensory or motor deficits. Patients with USN perform at a lower level than patient without USN on both cognitive and sensory-motor measures, show poorer recovery of motor function and are more impaired in activities of daily living [6,7]. Although the relation between neglect and motor recovery after stroke is still unclear, it does appear that treatment of neglect can facilitate the improvement of patients' motor and functional capacities [8].

A lateral deviation of the walking trajectory is often observed in stroke patients with USN and bumping into objects or doorposts during locomotion is considered a major problem in these patients [9]. Because they are key aspects to navigate safely through the environment it is important to investigate heading control and straight-line walking in neglect patients. However, existing research appears to be contradictory regarding the direction of the lateral deviation during walking. Reported deviations of the walking trajectory of stroke patients with a left USN are to the right [10,11] but also to both sides [12] and further it is reported that neglect patients show a tendency to collide with objects on their neglected side [13,14]. In the study in which deviations to both sides were observed [12] it appeared that the severity of the USN determined to which side patients deviated. While walking through a doorway patients with a mild left USN bumped into the left-hand side while patients with more severe left USN bumped predominantly into the right-hand side.

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In all these experiments, however, the task which the patients had to perform was either walking through a doorway or the task was vaguely described. To our knowledge no experiment has been performed in which patients with USN were asked to walk in a straight line towards a clearly defined target with no, or little, other distractors present in the environment. Differences in the richness of task environment can cause the use of different strategies for heading control such as the use of optic flow vs. the use of target location [15,16]. Possibly differences between performed tasks may account for the contradictory results in the above-mentioned studies. Furthermore, these studies do not mention the exact shape of the complete walking trajectory in the transverse plane. Deviations are generally measured at one specific point, e.g. the distance that subjects deviate from a doorpost while walking through a doorway.

Karnath demonstrated in a laser pointing task [17] that stroke patients with USN systematically displaced their subjective orientation of the sagittal midplane to the ipsilesional side. This finding is supported by the results of prism adaptation studies which also found that neglect patients displaced their subjective body midline to the ipsilesional side [18]. It is known that prism adaptation can induce neglect-like behaviour in healthy subjects [19,20]. Inducing a shift of the visual field by means of prism glasses, and with that inducing a heading error between the subject's heading and the correct heading, causes healthy subjects to walk towards a target describing a curved walking trajectory [15,21].

In the present study the walking trajectory of patients with USN will be recorded while they walk towards a clearly visible and well-defined target, while all other visual distractors have been removed from the task environment. When asked to walk towards a target in a straight line in these conditions, subjects need to constantly align their subjective body midline with the target, because no other visual cues that could be used for heading control are present. Since the displacement of the subjective body midline in patients with USN is to the ipsilesional side, they will, initially, need to rotate their objective body position to the contralesional side to align their subjective body midline with the target. This rotation towards the contralesional side will introduce a heading error between the patient's heading and the correct heading. Analogous to the curved walking trajectory of healthy subjects wearing prism glasses, we expect that it would cause patients to walk towards the target while describing a curved trajectory to the contralesional side.

2. Subjects and methods

2.1. Subjects

We studied 12 right hemisphere stroke patients, eight left hemisphere stroke patients and 10 healthy age matched

control subjects. Patients were included from an inpatient rehabilitation centre and had to be within 20–80 years of age, to have suffered a first time single unilateral stroke and to have no pre-morbid disorders that may have interfered with the aims of the present study. None of the healthy control subjects had a history of motor, vestibular or neurological disorders that may have interfered with the aims of the present study. Control subjects were recruited through local newspaper advertisements. The study was approved by the hospital's ethics committee and a written informed consent was obtained from each subject.

2.2. Procedure

The experiment was carried out in a quiet and “stimulus-poor” room of 7.8 m × 4.0 m. Apart from the targets the room was empty and no salient details were present on the walls. Subjects were instructed to walk towards a ball with a diameter of 10 cm that was positioned at a height just above each subject's head on each side of the room. The distance between the balls was 6.5 m. Subjects were instructed to constantly focus on the ball and to walk at a self selected comfortable speed towards the ball in a straight line, stand still underneath it, turn around, focus on the ball on the opposite side and walk towards it again in a straight line. If the walking ability of a subject allowed it, this procedure was repeated eight times (resulting in 16 walking trials). A two-dimensional ultrasonic positioning system (adapted version of a motion analysis system [22]) registered the position of the walking subject. The positioning system was attached to a belt around the waist of the subject, close to the centre of mass. Data from this device were recorded using a 200 Hz sampling frequency and further processed on a personal computer using Matlab 5.3. Time related samples were converted to position related X, Y-coordinates with a resolution of 5.0 mm in the X-direction (direction in which subjects walked) and 4.0 mm in the Y-direction (direction of lateral deviation).

2.3. Assessments

All patients were tested for the presence of USN by means of the Bells test [23], Schenkenberg's line bisection test [24], a letter cancellation task and a double simultaneous stimulation test to assess the presence of extinction (the failure to notice stimuli on the neglected side when simultaneously stimulated from both sides). The number of tests on which a patient showed neglect marked the neglect score. A neglect score of 0 was required to be classified as having no neglect. Patients who scored 1 or higher were classified as neglect patients. Walking ability was quantified in terms of walking speed, the Rivermead mobility index (RMI) [25] and the functional ambulation categories (FACs) [26]. Walking speed was calculated as the mean walking speed over the middle 4 m of the walked trajectory.

2.4. Dependent variables and statistic analysis

For each subject the separate walking trajectories were averaged to a single mean walking trajectory. The absolute maximum lateral deviation (AMLD) was used to quantify the amount a subject deviated from a straight walking trajectory. Differences in mean values between groups were tested with one-way analysis of variance (ANOVA) followed by Tukey's post hoc analysis when a significant between groups effect was found.

To explore possible differences in the walking trajectory within the group of neglect patients, the (signed) maximum lateral deviation (MLD) was calculated. Whereas AMLD only quantifies the amount a subject deviates from a straight walking trajectory, regardless whether this deviation is to the left or the right, MLD also provides information about the direction of the deviation: MLD is negative for deviations to the left and positive for deviations to the right. Scatterplots of MLD vs. comfortable walking speed, RMI, FAC and neglect score were observed and, if appropriate, Pearson's *r* correlation coefficient or Spearman's rank-order correlation coefficients were calculated.

3. Results

Six of the 12 right hemisphere patients showed neglect on one or more neglect tests, whereas no left hemisphere patients showed signs of neglect. In Table 1 the characteristics of the resulting groups are presented. No significant between groups effect was found for age [$F(3, 26) = 1.50$; $P = 0.237$]. A significant between group effect was found for comfortable walking speed [$F(3, 26) = 5.44$; $P = 0.005$]. Tukey's post hoc test showed that all patients walked significantly slower than the healthy control group (stroke left, no neglect: $P = 0.036$; stroke right, no neglect: $P = 0.008$; stroke right, neglect: $P = 0.006$). There were no significant differences in comfortable walking speed between patient groups. For the three patient groups a significant between group effect was found for time post stroke [$F(2, 17) = 4.10$; $P = 0.035$], however, post hoc analysis did not show any significant

differences. The RMI and FAC did not show any significant group effects.

A significant between group effect was found for AMLD [$F(3, 26) = 9.90$; $P < 0.001$]. Tukey's post hoc test showed that the neglect group significantly differed from all other groups (neglect group compared to: healthy controls: $P < 0.001$; stroke left, no neglect: $P = 0.001$; stroke right, no neglect: $P = 0.003$). Healthy controls, stroke left, no neglect and stroke right, no neglect did not significantly differ from each other (healthy controls vs. stroke left, no neglect: $P = 0.996$; healthy controls vs. stroke right, no neglect: $P = 0.918$; stroke left, no neglect vs. stroke right, no neglect: $P = 0.976$). Fig. 1 shows the mean walking trajectory for each subject per group. This clearly illustrates the large lateral deviation in the neglect group. However, the Figure also shows that not all neglect patients deviated to the same side.

The scatterplots in Fig. 2 show that it is justified to assume a linear relation, within the neglect group, between MLD and comfortable walking speed, RMI and FAC. Pearson's *r* correlation coefficient between MLD and comfortable walking speed is -0.898 ($P = 0.015$). Spearman's rank-order correlation coefficient between MLD and RMI is -0.926 ($P = 0.008$) and between MLD and FAC -0.828 ($P = 0.042$). No relation appears to exist between MLD and neglect score.

Fig. 1 shows that there was a subject in the stroke left, no neglect group with a somewhat larger MLD to the left and a subject in the stroke right, no neglect group with a somewhat larger MLD to the right. The fact that these two subjects were slow walkers made us inspect the scatterplots of MLD vs. comfortable walking speed for these groups and the healthy controls. The scatterplots are presented in Fig. 3. This does not show a relation between MLD and comfortable walking speed for the healthy control group but for the stroke left, no neglect group a positive linear correlation and for the stroke right, no neglect a negative linear correlation appears to exist. These correlations were moderate to high but just failed to reach significance at the conventional significance level of 5% (stroke left, no neglect: $R = 0.669$; $P = 0.070$; stroke right, no neglect: $R = -0.793$; $P = 0.060$).

Table 1
Demographic data, motor ability and absolute maximum lateral deviation

	Controls ($n = 10$)	Stroke left, no neglect ($n = 8$)	Stroke right, no neglect ($n = 6$)	Stroke right, neglect ($n = 6$)
Age (years)	56.5 (33.2–69.7)	55.9 (35.6–73.2)	59.5 (37.3–73.6)	67.5 (63.5–69.8)
Sex (M)	5 (50)	4 (50)	2 (33)	6 (100)
Time post-stroke (days)	n.a.	447 (202–692)	819 (485–1023)	406 (93–1066)
Motor ability				
Speed (m/s)	1.24 (0.09)	0.85 (0.43)	0.70 (0.33)	0.68 (0.39)
RMI	n.a.	12.5 (9–14)	11.5 (8–14)	11.5 (8–14)
FAC	n.a.	4.6 (4–5)	4.3 (3–5)	4.7 (4–5)
AMLD (m)	0.035 (0.011)	0.042 (0.021)	0.055 (0.034)	0.197 (0.136)

Values are mean (range), mean (S.D.) or *n* (%) as appropriate.

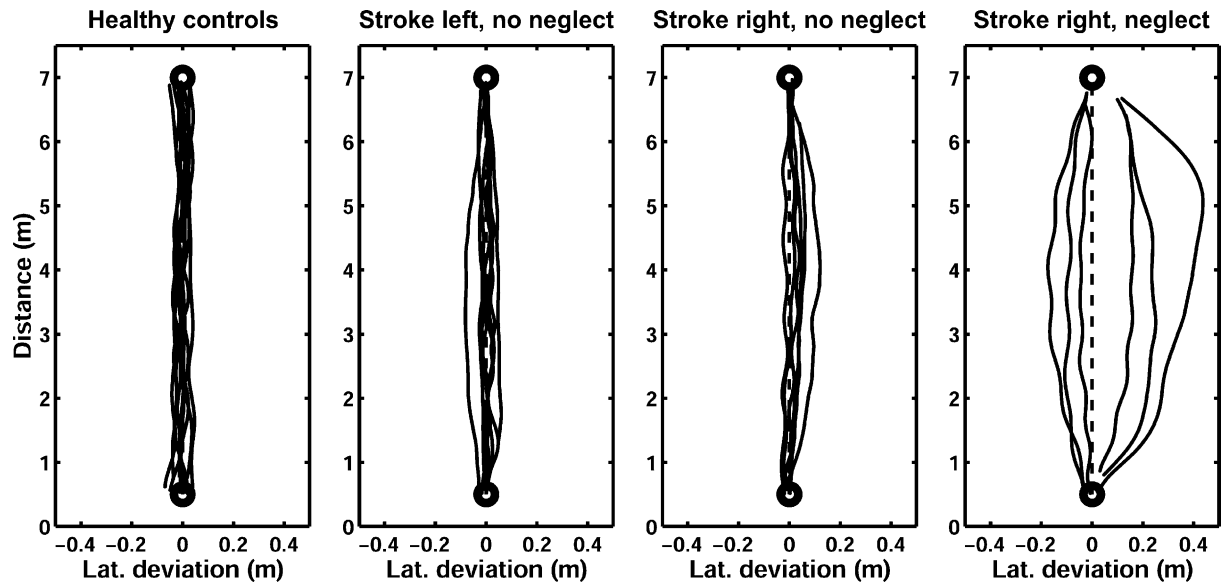


Fig. 1. Mean walking trajectory of each subject per group. The trajectories start in the lower part of the figure.

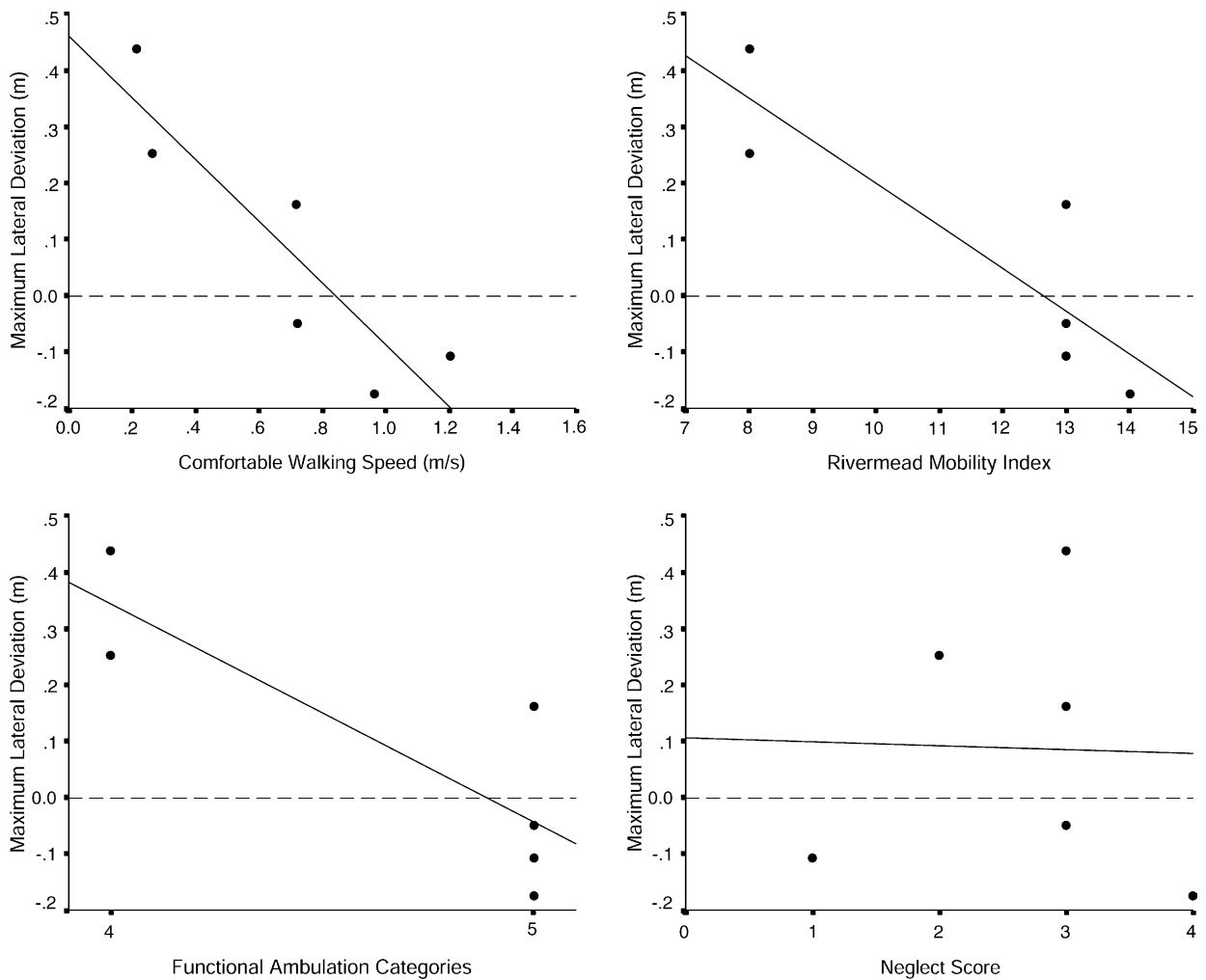


Fig. 2. Scatterplots of maximum lateral deviation (MLD) vs. comfortable walking speed, Rivermead mobility index (RMI), functional ambulation categories (FAC) and neglect score for right hemisphere stroke patients with neglect.

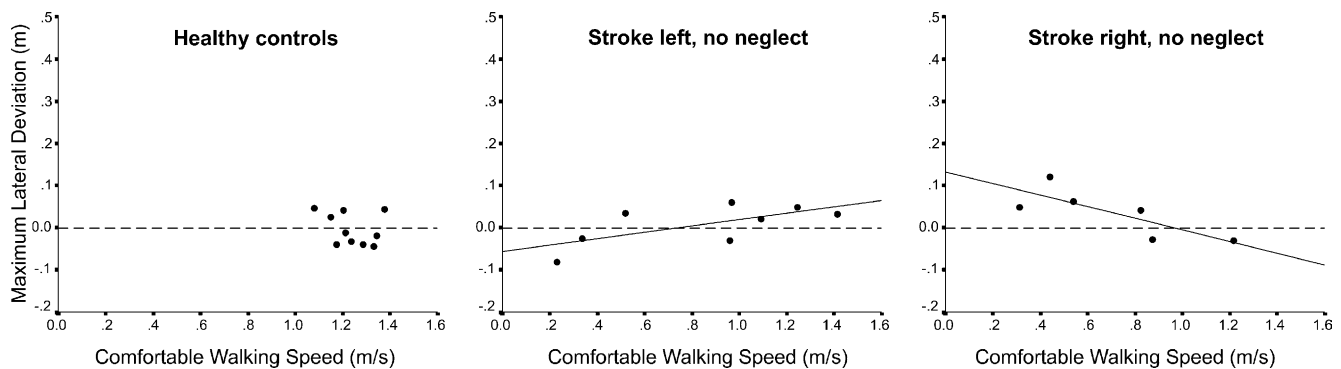


Fig. 3. Scatterplots of maximum lateral deviation (MLD) vs. comfortable walking speed for healthy controls, stroke left, no neglect and stroke right, no neglect.

4. Discussion

Stroke patients with USN showed a larger lateral deviation in their walking trajectory when they walked towards a target compared to stroke patients without USN or healthy control subjects. We expected that this deviation would have been to the contralesional side, i.e. the paretic side. However, this was only the case for three neglect patients; three other neglect patients showed a large deviation to the ipsilesional side, the non-paretic side. It appeared that there was a strong negative correlation between walking ability and lateral deviation. Neglect patients with good walking ability showed a deviation to the contralesional side, as we had expected. The more neglect patients' walking ability was impaired the more their deviation shifted to the ipsilesional side. Within the neglect group we found no relation between the severity of USN and the lateral deviation of the walking trajectory.

We suggest that the shift in lateral deviation due to walking ability can be explained by introducing the concepts of dual task and task priority. For patients with unimpaired walking ability, walking towards a target is a rather an effortless task. The task consists of walking and heading control, in which walking may be considered to be performed automatically while heading control is the primary task. The displaced subjective midline in neglect patients to the ipsilesional side introduces an error in heading control. Aligning their subjective midline with a target makes these neglect patients walk in a curved trajectory to the contralesional side, as we had expected. However, when walking ability is impaired, walking no longer is performed automatically. It becomes a consciously and actively monitored process that requires attention and the task priority of walking is increased compared to the task priority of heading control. The more walking ability is impaired, the more attention is required for the walking task, increasing its priority and eventually walking will become the primary task and heading control the secondary task. Rather than to control actively their heading, patients would now be concentrating on walking straight ahead, using a mental representation of space. This mental representation is

distorted in neglect patients. The displacement of the subjective bodyline to the ipsilesional side in neglect patients means that "straight ahead" is shifted to the ipsilesional side. Therefore, walking straight ahead will cause the patient to diverge to the ipsilesional side. Since heading control has become a secondary task patients will only adjust their heading occasionally. The more patients are limited in their walking ability the lower the task priority of heading control will be and the less often patients will adjust their heading. This will result in a larger lateral deviation to the ipsilesional side.

Tromp et al. [12] suggested that the severity of the USN determined to what side patients deviated. In their study patients with a mild left USN bumped into the left-hand side of a doorway while patients with more severe left USN bumped predominantly into the right-hand side of the doorway. However, it can be deduced from the data they presented in their article (Table 1, p. 322) that the patients who deviated to the ipsilesional right also were the slowest walkers. Therefore, the effect they found may in fact be the same effect as found in our study. The apparent contradicting findings from other studies [10,11,13,14] may be caused by differences in walking ability between different neglect patients as well. Another cause may be found in the differences between the employed walking tasks. We suggest that differences in left- or rightward deviations of the walking trajectory in neglect patients is caused by using different strategies of heading control: walking straight ahead or aligning the subjective body midline with the target. Differences in task circumstances, such as the amount of visual stimuli and optic flow, or task instructions can cause the use of different strategies for heading control [15,27,28] and therefore cause different outcomes in the direction of lateral deviations in neglect patients' walking trajectory.

A trend appeared to exist between walking speed and lateral deviation in the no-neglect groups: the slower walkers showed a larger deviation to the ipsilesional, non-paretic side. We suspect that it was the attachment of the positioning system around the waist of the subjects together with characteristic hemiparetic gait in some stroke patients that

may have caused this trend. Compensations such as a hip hike [29,30] and the avoidance to bear weight on the paretic limb [31], cause a shift of the waist to the ipsilesional, non-paretic side. Our positioning system measured this shift as a deviation of the walking trajectory. This effect may, of course, have been present in the neglect group as well and it would have increased the lateral deviation to the ipsilesional right in the patients whose walking ability was impaired. However, the possible effect of the waist shift in the no-neglect groups was far less than the deviation found in the neglect group and would, therefore, only have increased the found effect slightly. In future research it could be taken into account, however, by measuring the walking trajectory of the feet instead of the waist.

Future research should further investigate the relation between neglect, walking ability and lateral deviations in the walking trajectory, to yield data which could determine if recovery of walking ability in neglect patients changes their walking trajectory deviation from the ipsilesional side to the contralesional side and if neglect training such as prism adaptation, which is specifically aimed at restoring the displaced subjective midline, also improves the walking trajectory in neglect patients.

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